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GALILEO. COPERNICUS, AND THE TIDES

Galileo's endorsement of Copernicus' helio-centric theory of the structure of the universe presents a good test of two popular views about scientific methodology: (1) scientists prefer a theory which can solve problems it was not invented to solve. And (2) scientists prefer a theory which can solve problems not solved by its predecessor. Let us call (1) the Accidental Thesis (AL) and (2) the Predecessor Thesis (PL). Where Galileo is concerned, both AL and PL are supportable in varying degrees depending on some qualifications. The story shows that the problem Galileo sought to solve, the ebbing and flowing of the seas, i.e. the tides, required the motions of the earth dictated by Copernicus' theory but denied in Ptolemaic theory. Before dealing with the specific theses, two issues need to be addressed. (1) Why this particular case was picked to illuminate the issue of theory appraisal, and (2) the status of Copernicus' view. Following the discussion of these issues we will examine the development of Galileo's account of the tides. This will leave us with our final question: why did Galileo choose the particular theory of the tides he defended?

1. THE RELEVANCE OF THE GALILEO-COPERNICUS CASE

The period known as the Scientific Revolution extends roughly from the date of the publication of Copernicus' *De Revolutionibus Orbis* (1543) to the publication of Newton's *Principia* (1687). Between those dates many changes took place before the new view of the universe, its structure and the forces behind it replaced the old Aristotlean cosmos [1].

[1] I have chosen this way of identifying the time period because we at least have these two dates. It should be noted, that the mere publication of a book is not sufficient for it to be a major event. It must be recognized, publicized, endorsed, etc. Thus, if it were possible, we should wait to fix the terminating date of the Revolution at the point where it is clear that Newton's theory, as expressed in Principia, was accepted over its rivals. But it is not clear that we can on's theory, as expressed in Principia, was accepted over its rivals. But it is not clear that we can those particular dates and books are so important.

The most important change was the development of an alternative to Aristotle's account of motion (of both heavenly and earthly bodies). Copernicus gave us an alternative description of the motion of the planets — that was the first step. But before that description could be accepted as an adequate theory a new physics was also required that could account for the causes of those motions; that took a bit more doing[2].

The key to the development of the new physics was the use of mathematics to provide explanations of physics events. In accordance with the dominant intellectual tradition of the time, the subject matter of mathematics was quantity in and of itself — not quality or the properties of objects. The major obstacle to the new physics, therefore, was an effective prohibition of the use of mathematics to make claims about the world. What was acceptable was the use of mathematical reasoning *ex suppositions*, meaning by that something close to „on hypothesis". So as long as one did not claim that the real properties of objects could be addressed in mathematical terms, i.e. that mathematics did not reveal anything necessary about the world, one was playing by the rules[3]. But it is exactly the mathematization of experience that characterizes the development of modern science. This process begins in the late sixteenth and early seventeenth centuries with efforts to provide a mathematical account of the causes of the motions of the planets as described by Copernicus. It ends with the development of an entire new system of mathematics expressly for the purpose of dealing with the relations between physical events in general, incorporating along with it the helio-centric system.

Two major figures of the seventeenth century are primarily responsible for the ultimate success of the helio-centric view: Galileo and Kepler. Neither had a physics adequate to the job of explaining how the planets moved around the sun. Nevertheless, their efforts to provide a mathematical account of celestial phenomena, based on their acceptance and open advocacy of Copernicus' view contributed greatly to the intellectual climate which made Newton's achievement possible. While Kepler and Galileo both made substantial scientific contributions to the scientific revolution in their own right, in the long run it was their efforts in the

[2] The need for a new physics arose from the rejection of the geocentric point of view. Despite enormous difficulties in reconciling Ptolemy's method of computing the position of the planets with Aristotle's principle of circular motion as the only appropriate motion for the activity of the heavens, Aristotle's physics was, nevertheless, assumed in accounting for the motion of the planets. This made sense when combined with Aristotle's metaphysical view which argued for the central location of the earth on the basis of the nature of the elements. But once the earth is moved away from the center no principle of motion is available to explain its motion and the arrangement of the rest of the planetary system makes no sense, i.e. there is no theory to explain it.

[3] It is important to see that the issue here is not primarily one of science versus theology. In the universities there was an agreed upon ordering of the sciences and their domains. It is not so much that setting the earth in motion necessarily conflicted with theological dogma, which it did. There was a prior problem with the approach taken by both Galileo and Kepler: using mathematics to „explain" the motions was an inappropriate methodological procedure. See William Wallace, *Galileo and His Sources,* Princeton: Princeton University Press, 1984, pp. 99—147.

direction of a mathematical physics and the transformations that brought about in the original formulation of the Copemican theory that marks their place in the history of science. I belabor this point because it is crucial in understanding what Galileo actually did when we say, in accordance with our two theses, that he preferred Copernicus' theory.

The case of Galileo's rejection of Ptolemy in favor of Copernicus is relevant to issues in methodology for several reasons. First, it is a situation in which there is a clear-cut choice being made between two theories. Second, it is possible to show that Copernicus' concern was strictly with the astronomical phenomena, while Galileo's was with terrestrial problems (albeit, the latter may be a bit more controversial). Third, an adequate account of Galileo's relation to Copernicus reveals many of the complexities involved in the process whereby scientists use the work of others, which revelations should prove useful in clarifying our understanding of the Scientific Revolution and, hence, the nature of the development of modern science.

2. THE STATUS OF COPERNICUS THEORY

The issues here concern (1) whether or not Copernicus' view is to be considered a theory or a set of guiding assumptions, (2) the content of Copernicus' view, (3) its purpose.

Copernicus' view does not qualify as a set of guiding assumptions, but does qualify as a theory in the early seventeenth century. While the assumptions of helio-centricity and the triple motion of the earth may count as guiding assumptions today, they certainly didn't in 1632 (the date of Galileo's *Dialogue).* Today those assumptions are beliefs generally shared not merely by the scientific community but also by our culture, are embodied in current theories of astrophysics, specify the kinds of objects (planets and stars) and their domain (the heavens) and their motions (around the sun), as well as (in Copernicus' *De Revolutionibus,* p. 25) the cognitive goal (a correct description of the motions of the planets), are explicit at the outset and have central element (circular motion) which sometime change in piecemeal fashion.

But at the time Galileo publicly comes out in favor of Copernicus (1612/13), those assumptions are not shared by a community, and did not embody a stable mathematical core that was held immune from refutation. Kepler may come closest to allowing his acceptance of Copernicus' assumptions to guide his research. But that research was primarily concerned to find an alternative mathematical core. Where Galileo is concerned, Copernicus' assumptions are useful in achieving Galileo's own objectives, but did not constitute the model for solving his problems, nor did they provide criteria for solutions to his problems, nor where they concerned with the objects Galileo was concerned with. Thus, it seems that there is a time factor involved in the claim that something is or is not a set of guiding assumptions.

On the other hand, it seems fairly clear that the content of *De Revolutionibus* was and remains a theory about the structure of the universe. It presents a systematically related set of propositions about a specific domain of objects and details the methods for calculating the activities of those objects. Furthermore, the theory was developed from a set of guiding assumptions on the part of Copernicus. Those assumptions included items shared by the community of scholars at that time, such as agreement on the inadequacy of the current state of knowledge about the motions of the heavens. Based on that assumption, Copernicus refused to go to Rome to be involved in the reform of the calendar and set about attempting to correct the system which gave us the inadequate knowledge. In other words, guided by the assumption that the current astronomical theories were inadequate, Copernicus set out to produce a better theory, one more in accord with the requirements of mathematical rigor and the observational facts.

Given these facts and the total lack of mention of the tides in *De Revolutionibus* it seem reasonable to conclude that Copernicus' theory was not motivated by concerns of terrestrial physics.

3. GALILEO AND THE TIDES

In 1612 Galileo first heard of Kepler's elliptical orbits. In that same year he first gave public notice of his admiration of the Copernican system in the last of his *Letters on the Sunspots.* Speaking of the rings of Saturn he notes, „...this planet also, perhaps no less than horned Venus agrees admirably with the great Copernican system on which

propitious winds now universally are seen to blow to direct us with so bright a guide that little [reason] remains to fear shadows or cross- winds" [4]. But he does more than merely endorse the Copernican system, he uses it in his calculations. In an appendix to the *Sunspots* he attributes the cause of the disappearance from view of the moons of Jupiter to „the annual movement of the earth" [5]. He does not, however, justify his appeal to the Copernican system.

This is not to say that Galileo did not have a justification for his use of the Copernican system. We have an early hint as to what that justification may be in a letter he wrote to Kepler in 1597. In that letter he confesses that he is a Copernican and that by assuming the earth's motions he could explain some physical events which had not hitherto been accounted for satisfactorily. He does not tell Kepler what he had in mind and he also asks him not to reveal his support of Copernicus. But, it is clear his justification for adopting the Copernican point of view is his belief that it can be used to explain other events than the ones it has been used for. This suggests that the claim that scientists prefer a theory not invented to solve problems they have interest in AL may be correct in this instance. To determine this we need to find out what those other events Galileo had in mind were.

Following the publication of the *Sunspots* in 1613, Galileo was involved in a number of unfortunate incidents through which he became embroiled in arguments about the theological legitimacy of the Copernican system. This all came to a head in

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[4] I am using Drake's new translation here as found in Drake, Stillman, *Galileo At Work,* Chicago: Chicago University Press, 1978, p. 198. It should be noted that Galileo's claim here about the reception of Copernicus is just so much propaganda. There is clearly no evidence of universal acceptance.

[5] Ibid., p. 208.

late February 1616 when a special Papal commission found against the Copernican ideas of the motion of the earth. Galileo was warned not to teach or defend Copernicus any longer. But prior to that (January 1616), while in Rome for the express purpose of clearing his name and arguing against the suppression of Copernicus, Galileo wrote out his theory of the tides. As Drake correctly notes, this theory was intended to be a Copernican argument[6]. That means it assumed the chief principles of the Copernican system and did not argue for them. The little treatise on the tides was put away after the subsequent Church finding against Copernicus. However, the 1616 treatise on the tides resurfaces in 1632 as the fourth and final Day of Galileo's *Dialogue on the Two Chief World Systems.*

So war we know the following: from 1612 to 1616 Galileo was a public advocate for the Copernican system. What we do not know is exactly why. We have a hint: by assuming the Copernican system other things can be explained. If there is anything like a standard or commonly accepted view of Galileo's justification for this choice of the Copernican system over the Ptolemaic, it is the view that this justification is to be found in his *Dialogue.* I agree that whatever justification Galileo provides for the Copernican system is to be found in the *Dialogue.* But, the nature of that justification needs to be examined. For if the standard view of that argument is correct, then we would be forced to conclude that Galileo did not support Copernicanism because of either AL or PL. On the other hand, reading the *Dialogue* as it was intended by Galileo produces the opposite result.

The *Dialogue* is divided into four Days. In his preface, Galileo outlines his argument as it develops over the course of the book. After explaining that the Copernican system has been banned and that it has been suggested by some that this is due to ignorance of the scientific findings of Copernicus, Galileo asserts his purpose to be „to show to foreign nations that as much is understood of this matter in Italy, and in particular in Rome, as transalpine diligence can ever have imagined" [7]. He acknowledges he has taken the side of Copernicus, and intends to show the superiority of Copernicus' view „not absolutely, but as against the arguments of some professed Peripatics". Galileo appears to be aiming at a rather low target. He claims not to intend to prove the Copernican system correct, but only to argue against the arguments of those who oppose it. He then gives us the three topics he wishes to address: in Day Two he shows that any experiment conducted on the earth determines nothing about the motion or lack of motion of the earth. In Day Three he intends to examine the „celestial phenomena" in a way deigned to strengthen the Copernican position. And finally in Day Four he proposes „...an ingenious speculation. It happens that long ago I said that the unsolved problem of the ocean tides might receive some light from assuming the motion of the earth" [8]. How long ago did Galileo mean? We already know about the unpublished 1616 treatise.

[6] Drake, op. cit., p. 252.

[7] Galileo Galilei, *Dialogue Concerning the Two Chief World Systems,* Berkeley: University of California Press, 2nd revised edition, 1967, p. 5. Translated by Stillman Drake.

[8] Galileo, op. cit., p. 6.

But it turns out that Galileo had first worked out those ideas as early as 1595 [9].
So it seems that Galileo had long employed Copernican assumptions to deal with a problem of equally long standing [10].

There is little disagreement concerning Day Two. There Galileo rehearses a large number of arguments concerned with demonstrating that on the earth it is not possible to prove the earth's motion or lack of it. This means that if one is going to prove that the central contentions of the Copernican theory are correct, one cannot appeal to terrestrial experiments.

On the standard interpretations of Day Three, Galileo argues for the Copernican system by showing its superiority to the system of Ptolemy. But that is not what Galileo does. Rather he argues for the superiority of the Copernican system by demonstrating the ineffectiveness of the arguments against it. Most of those arguments are by philosophers, not scientists, based on appeals to the authority of Aristotle. He also manages to sprinkle his refutations with references to his own telescopic discoveries as supporting evidence for Copernicus. But it is difficult for Galileo to use his discoveries as compelling evidence without begging the question of what constitutes adequate evidence [11].

In Day Four Galileo presents us with his explanation for the tides. This consists in showing how the compound motions of the earth (annual rotation around the sun and daily rotation around its axis) produce a sloshing of the waters of the seas, hence the tides. This theory has often been ridiculed since it produces only one high and one low tide a day. Thus, to correct for what the observational data shows us, that there are two of each, Galileo is forced to appeal to such „secondary factors" as the weight of water. Given the *ad hoc* solution Galileo produces, there has been some question as to the role of Day Four and the theory of the tides. This worry is further exacerbated by the fact that according to Galileo, if one assumes the Copernican motions for the earth, then one can explain the tides and this should in turn be support for the Copernican system. On the surface this is a blatantly circular argument, which, furthermore, Galileo acknowledges. He even puts the circularity objection in the mouth of Simplicio, the Aristotlean simpleton and then, to confuse matters, Galileo doesn't answer the charge.

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[9] Galileo, op. cit., p. 6.

[10] See Stillman Drake, *Telescopes, Tides, and Tactics,* Chicago, University of Chicago Press, 1983, p. xvii. There is some controversy here. Drake attributes his claim to the existence of an outline of Galileo's theory as developed in 1616 in the notes of Fra Paolo Sarpi from 1595. William Shea claim it is Sarpi's theory. See Shea, Galileo's *Intellectual Revolution,* New York: Neal Watson, 1972, p. 173 and Drake, *Galileo At Work,* p. 37. I side with Shea. See „Heavens and the Earth; Bellarmine's influence on Galileo," J. C. Pitt, in *Continuity and Revolution,* edited by P. Barker and R. Ariew, Washington, DC: Catholic University Press (forthcoming).

[11] Of course, prior to his publication of the *Starry Messenger* and the *Sunspots* he had no need to make his support of Copernicus public since up till then he was concerned primarily with problems of terrestrial physics. It wasn't until Galileo made known his telescopic discoveries and began to pursue arguments for the similarity of features on the moon to those on the earth and the corruptibility of the heavens that he needed a theory of celestial phenomena. And then within the short space of fours years he is forced to suppress his Copernicanism.

This seems very strange, since Galileo is sensitive to charges of faulty reasoning.

All of the above suggests it is difficult to read the *Dialogue* as Galileo's justification for accepting the Copernican system over the Ptolemaic. It seems doubly strange when one also considers the following two factors. (1) The Copernican system is an *astronomical* theory. It is proposed by Copernicus as a more accurate alternative to the Ptolemaic astronomy. Most of Galileo's argument for Copernicus in the *Dialogue* (if it is to be read that way) consists of arguments against Aristotlean *cosmology*. (2) The subject matter of the *Dialogue* as originally proposed by Galileo was the tides, not a defense of Copernicus. Let us consider this latter point in some detail.

Galileo's original title for the *Dialogue* was *Dialogue on the Ebb and Flow of the Seas*[12]. It and the original Preface were changed at the order of the Pope. In addition the opening speeches introducing the topic of the book as the tides were omitted. The result was the title we now have, which as originally printed read „Dialogue of Galilei Galileo Licean, Mathematician Extraordinary, from study at Pisa, and philosopher and Primary Mathematician to his most serene Grand Duke of Tuscany, during which meetings over four days are discussed arguments about the two Great Systems of the World, Ptolemaic and Copernican, putting forth without resolution the philosophical and natural arguments for one and against the other (My translation)[13].

If we read the *Dialogue* as concerned primarily with presenting a theory of the tides we can begin to explain Galileo's lack of concern over the charge of circularity. But only if we add an additional factor will this work completely. That factor is Galileo's theory of justification. Furthermore, by taking this into account we can also explain what is going on in Day One. The discussions of Day One are usually ignored. A large part of the time is occupied with showing the similarities between the earth and the moon. The question is what does that have to do with the tides and Copernicus? The relevance to Copernicus is straightforward. Those arguments contribute to the claim that there is no necessary difference between the earth and other celestial bodies as maintained in Aristotlean cosmology. But there is more going on there as well.

The major point of Day One is to argue for the method of geometric proof combined with appeal to experiment and observational data over appeal to Aristotlean discursive first principles as the most appropriate means of justifying conclusions. Throughout the rest of the book Galileo continues to argue for and develop this method, replacing Aristotlean proofs with appeals to geometry and interpreting them by means of examples drawn from terrestrial phenomena. Where there are no Aristotlean proofs, he simply provides geometric ones. The total effect is a systematic vindication of his

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[12] Elsewhere I have argued that the *Dialogue* is to be read as a sustained argument for a different kind of argumentation in science — one using geometric demonstration and appeals to terrestrial phenomena as a basis for explaining physical events both on earth and in the heavens (Joseph C. Pitt, *Galileo, Justification and Explanation* in Philosophy of Science, Vol. 55, No. 1, 1988, pp. 87— 103, and *The Character of Galilean Evidence,* PSA 1986, pp. 125—134). This is opposed to the Aristotlean appeal to metaphysical first principles and reasoning from *a priori* definitions. Even in Day Three Galileo knows he cannot assume he has made his case for the admissibility of his telescopic evidence, even though he relies on the persuasiveness of his rhetorical devices to bully his way through.

[13] Most of the factual material here is based on the detective work of Stillman Drake and can be found in his *Galileo At Work,* and in *Telescopes, Tides, and Tactics.*

geometric method, so that by the time he comes to the tides, the fact that by geometric factors (and two fairly slick terrestrial examples) he can show that compounding the motions of the earth can produce the tides constitutes its own justification. In other words, the charge of circularity does not bother Galileo because he is operating on the principle that the ability to provide an explanation using terrestrial examples and geometric demonstrations vindicates prior assumptions. This is the methodological principle he spends the first three days of the *Dialogue* developing. Galileo therefore vindicates his assumption of the Copernican principles of the motions of the earth by showing how using them can explain a phenomenon that had not been solved by its predecessors thereby substantiating PL.

4. ALTERNATIVES TO GALILEO'S THEORY OF THE TIDES

The question remains: why did Galileo choose the theory of the tides offered in Day Four of the *Dialogue?* There were alternative theories available. They come in two categories: (a) those which involved the motion of the earth and (b) those which did not. Despite the availability of alternatives, the answer to our question is simple: none of them met Galileo's conditions of adequacy. For a theory to be acceptable to Galileo it had to: (1) be amenable to geometricization; (2) not appeal to occult forces; (3) permit the measurement of processes and relationships postulated by the theory. Let us take a brief look at the available theories and see how they stack up[14].

Of those theories which attempted to explain the motion of the tides while keeping the earth stationary the most prominent is the one Aristotle's defenders used. It maintains that the cause of the tides is the slope of the ocean floor and the wind. Galileo's objection here would be the same as his objection to the theory of Marcantonio de Dominis, although for slightly different reasons. He attacks de Dominis' theory in Day Four because of its appeal to the attraction of the moon. Galileo's objection to occult forces comes in here, but more importantly he argues that such forces would have to apply to the whole ocean, raising it all at the same time. But, according to Galileo, the water is raised only at the edges. As Shea point out this is an effect only on Galileo's own theory![15] But the same point would be involved here with the Aristot- leans. For the wind to cause the effect the ocean would have to be higher in the center. More to the point, Galileo's general objection to the Aristotelian account is based on rejection of its methodology [16].

A second theory that was available, although not in vogue, was that of Apollonius. It provided an animistic interpretation of the tides based on an analogy with respiration. The occult causes objection would also be raised here.

There were also variations of the moon attraction or effect theory due to Scaliger, Borro and Telesio. But these would all be rejected by Galileo on the basis that appeals to sympathy between the earth and moon or the heating of the seas by the sun appeal to

[14] See Pitt, *Galileo, Rationality and Explanation.*

[15] William Shea has produced a nice summary of the available alternatives in his *Galileo's Intellectual Revolution.* My account here is deeply endebted to his research.

[16] Shea, op. cit,, p. 179.

vague and unmeasurable concepts.

A theory which suggested the earth moved was proposed by Cesal- pino. But there was no accountable cause for the motion which was consistent with the basic Aristotlean framework he invokes.

So it seems that while there were alternatives to the theory Galileo proposed, none of them met his conditions. Nevertheless, that does not answer the question of why Galileo produced the theory he did and then continued to defend it despite its problems. And, unfortunately, there is no record of Galileo’s reasons.

Therefore, let me propose the following speculative answer. Galileo’s theory of the tides did not require any causal agency other than the motions of the earth. It was the causal simplicity of his theory that kept him wedded to it. In defense, recall that the lack of an adequate celestial physics to account for the motion of the planets was a major obstacle to the wholesale acceptance of Copernicus’ theory. If Galileo could devise an account of the tides based only on the assumptions of the earth’s motions that would, in effect, take the bite out there not being a full causal explanation available. No other theory available relied on so little. Thus. Galileo’s theory of the tides seems to be a result of his methodological criteria. There is one final piece of evidence in favor of this conclusion.

If it is the case that Galileo first devised his theory of the tides as early as 1595, but didn't develop it until 1616, it could be argued that this tardiness was a function of his not having fully developed his methodological criteria when he first hit on the basic idea of his tidal theory. In other words, if the methodology in some sense explains Galileo's adherence to his strange theory, the delayed public announcement of that theory can be attributed to the time it took him to develop his own methodology to the point where he felt comfortable applying it to celestial considerations. So far this continues to be more speculative than factual. But there is some evidence we can produce. Thanks to William Wallace’s extensive labors [17], we now know that Galileo was studying Aristotlean methodology as late as 1591. Having become acquainted with Copernicus work and that of Archimedes at roughly the same time, there is good reason to suppose that Galileo’s methodological sense was somewhat in turmoil. Given the conflicting pressures these traditions represented, it makes good sense to think it took Galileo some time to work out his defense of the methodology he uses in his theory.

5. CONCLUSIONS

AL claims that scientists prefer a theory which can solve problems it was not invented to solve. There is no evidence that Galileo preferred Copernicus to Ptolemy specifically because it was a theory that could solve problems it was not invented to. With regard to this thesis, the most that can be said is that Galileo choose the Copernican theory because on its assumptions he could explain the tides with minimal appeal to causes. Thus, while he did prefer a theory which did solve a problem it was not intended to, it is not clear he choose the theory for that singular reason.

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17 Wallace, op. cit.

PL says that scientists prefer a theory which can solve problems not solved by its predecessors. The theories of the tides available to Galileo did not solve the problem of the tides on *his* criteria. It is important to see that there was available a viable Aristotlean solution consistent with Aritotlean principles. Galileo's objection to this solution was tied to his methodological objections to Aristotlean methodology. To the extent that Aristotlean physics as practised by Galileo's contemporaries produced poor results, results which Galileo could correct and improve upon was reason enough for him to advocate his method and reject the Aristotlean. With his rejection of the Aristotlean framework, the Aristotlean solution to the tides went out. In addition he had a technical, although bad, reason against it.

The case with Galileo's preference of Copernicus over Ptolemy is less complicated. It appears that Galileo became a Copernican because the Copernican theory supported his solution to the tides. Thus it would appear that since the problem of the tides had not been solved to Galileo's satisfaction, and since on assuming the Copernican motions of the earth, he could produce a theory of the tides which met his conditions, then we can say he preferred Copernicus to Ptolemy because the Copernican theory could be used to solve a problem not solved by its predecessors.